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We proposed studying plasma physics processes occurring in magnetospheric plasmas by means of numerical simulations. This study has included the excitation of instabilities due to electron currents and/or ion beams due to the presence of nonuniform electric fields. Our investigations also included the heating and transport of plasma in the presence of particle interactions with excited waves in a collisionless plasma. Extensive numerical simulations have been performed along with the development of analytic theories. These simulations allowed us to assess the affect of inherent nonlinear processes on plasma dynamics and to compare the simulation results with the observed data. Keywords

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I. RESULTS FROM PRIOR SUPPORT

1. Simulation Study of a New Mechanism for Excitation of Kinetic Waves in a Magnetoplasma

Nishikawa *et al.* [1988] have investigated the new ion-cyclotron-like waves by a localized transverse electric field by means of simulation with the assistance of the nonlocal kinetic theory. The linear theory shows that the growth rates of the kinetic Kelvin-Helmholtz (K-H) modes are strongly reduced with increasing $u = k_{||}/k_y$, and they become unstable only when $b = k_y^2\rho_i^2 < 1$ and $k_yL \approx 1$, where L is the scale length associated with the transverse electric field. On the other hand, the new modes have larger frequencies and become unstable at larger $b > 1$ and $k_yL \gg 1$ [Ganguli *et al.*, 1988].

Simulation results show that ion-cyclotron-like waves are excited in regions where $\mathbf{E} \times \mathbf{B}$ drift is localized. Linear growth rates of several modes are obtained from the wave analysis of the simulation. This linear analysis shows that the (0, 4) mode corresponds to large b, and large k_yL has the maximum growth rate. Clearly, these are not K-H modes. Further, the simulation results show that density gradients help to enhance the growth rates. However, like the K-H mode, the real frequencies of this instability are approximately proportional to $k_yV_E^o$, where V_E^o is the peak value of the $\mathbf{E} \times \mathbf{B}$ drift.

Nonlinear phenomena such as diffusion and coalescence of vortices are investigated. In the linear stage smaller vortices are generated and larger vortices with the lower frequencies are dominant in the nonlinear stage. In the nonlinear stage ions diffuse strongly due to large-scale vortices.

Recently, we have investigated the electrostatic waves driven by the combined effects of a localized transverse electric field and parallel electron drifts by means of simulation with the assistance of the nonlocal kinetic theory [Nishikawa *et al.*, 1989b].

We have performed a number of simulations for this instability. Simulation results show that electrostatic waves are excited in the regions where the $\mathbf{E} \times \mathbf{B}$ drift is localized in the simultaneous presence of parallel electron drifts and transverse electric fields. Simulations with only parallel electron drifts or transverse electric fields show that no instability grows out of the thermal noise. The simulation with both the parallel electron drift and the transverse electric field shows the growing waves out of the thermal noise. The Doppler shift due to the $\mathbf{E} \times \mathbf{B}$ drift can lower the phase velocity of waves along the magnetic field. Then this makes wave-particle resonance possible for smaller V_d^o, which leads to this instability.

The nonlinear phenomena such as diffusion and coalescence of vortices are investigated. In the linear stage, smaller vortices are generated and larger vortices with the lower frequencies are dominant in the nonlinear stage. In the nonlinear stage the ions diffuse strongly due to the large scale vortices.

2. Beam Instability in the Foreshock

As an application of the simulation method used in the proposed research (Broadband electrostatic noise), the beam instability in the foreshock has been investigated. Electrons backstreaming into the Earth's foreshock generate waves near the plasma frequency by the beam instability. Two versions of the beam instability exist: the 'reactive' version in which narrowband waves grow by bunching the electrons in space, and the 'kinetic' version in which broadband growth occurs by a maser mechanism [Cairns, 1887a, b, and references therein]. Recently, Cairns [1987b] has suggested that (1) the backstreaming electrons have steep-sided 'cutoff' distributions which are initially unstable to the reactive instability, (2) the back-reaction to the wave growth causes the instability to pass into its kinetic phase, and (3) the kinetic instability saturates by quasilinear relaxation.

Cairns and Nishikawa [1989] have performed two-dimensional simulations of the reactive instability for Maxwellian beams and cutoff distributions. The results of the simulations are consistent with suggestions (1) and (2) above. In addition, we have demonstrated that the reactive instability is a bunching instability, and the reactive instability saturates and passes over into the kinetic phase by particle trapping. We found that the kinetic growth occurring after saturation of the reactive instability is presumably due to the spatially localized gradients in $y - v_{\|}$ phase space. Both simulation results and numerical solutions of the dispersion equation indicate that the center frequency of the intense narrowband waves near the foreshock boundary may be between $0.9\omega_{pe}$ and $0.98\omega_{pe}$, rather than being above ω_{pe} as previously believed.

3. Whistler Mode Driven by the Spacelab 2 Electron Beam

During the Spacelab 2 mission while an electron beam was being ejected from the shuttle. the Plasma Diagnostics Package (PDP) detected a clear funnel-shaped emission that is believed to be caused by whistler-mode emission from the electron beam [Gurnett *et al.*, 1986]. In order to understand the mechanism of this emission, the simulations have been performed using a three-dimensional magnetostatic code for low-β plasmas in which the beam electrons are initially located in the column [Nishikawa *et al.*, 1989a]. In order to simulate the continuous electron ejection from the shuttle, the simulations were also performed with the recycling of the beam electrons. The beam electrons excite whistler waves and lower hybrid waves. The brief fluid theory based on the magnetostatic code was checked with the simulation results. The propagating whistler mode was identified with the theory. The simulation results show that the quasi perpendicularly (the angle between the magnetic field and the wavenumber is larger than 50°) propagating whistler waves have larger amplitude whose real frequencies are smaller than the local electron cyclotron frequency. This fact is consistent with the fact that the funnel-shaped emission is observed below the electron cyclotron frequency away from the beam electron. The beam electrons initially in the column diffuse radially as well as slow down due to the $\mathbf{E} \times \mathbf{B}$ caused by the excited waves. The acceleration of the beam electrons also takes place due to the excited whistler waves.

In order to compare with the PDP data, the local magnetic fields $B_{x,y}$ and the perturbed electric fields $E_{y,z}$ are diagnosed at the several points in the simulation system. The results show that the waves are radially excited by the beam electrons localized in the center of the

system. The wave spectra of the electric fields $E_{y,z}$ diagnosed at $x = 31\lambda_e, y = 16\lambda_e$, and $z = 17\lambda_e$ show the several kinds of waves generated by the beam electrons. The analysis shows that the lower hybrid waves and whistler waves are excited. The frequency range of these spectra extends from ω_{pi} to beyond ω_{pe} which is in qualitative agreement with the PDP data. As the PDP data show, the intense electrostatic narrowband emission around the electron plasma frequency has been observed dominantly in the spectra of the electric field (E_z) with and without the recycling of the beam electrons. This wave is identified as the parallel (quasi parallel) whistler wave. This simulation result is in good agreement with the PDP data [Gurnett *et al.*, 1986]. The spectra of the magnetic fields diagnosed at the same position show that whistler modes are excited. The cB/E was calculated for the whistler mode. In the case without the recycling of the beam electrons, the cB/E is approximately 0.35 for the whistler mode (around $0.368\omega_{pe}$), which is smaller than that calculated from the PDP data [Gurnett *et al.*, 1986].

II. PUBLICATIONS FROM PRIOR SUPPORT (as of March 14. '989)

Nishikawa, K.-I., G. Ganguli, Y. C. Lee, and P. Palmadesso,

Simulation of ion-cyclotron-like modes in a magnetoplasma with a transverse inhomogeneous electric field, *Phys. Fluids*, *31*, 1568, 1988.

Nishikawa, K.-I., L. A. Frank, and C. Y. Huang,

Three-dimensional simulation of whistler mode excited by the Spacelab 2 electron beam. *J. Geophys. Res.*, *94*, ?, 1989a. (in press)

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Nishikawa, K.-I., G. Ganguli, Y. C. Lee, and P. Palmadesso, Simulation of electrostatic ion instabilities in the presence of parallel currents and transverse electric fields, *Physics of Space Plasma (1988), SPI Conference Proceedings and Reprints Series, Number 8*, T. Chang, G. B. Crew, and J. R. Jasperse, eds., Scientific Publishers, Inc., Cambride, MA, 1989b, p. (in press).